GREY WATER HEAT RECOVERY SYSTEM

with funding provided by

Alberta

DEPARTMENT OF HOUSING

Innovative Housing Grants Program

GREY WATER HEAT RECOVERY SYSTEM

MARCH 1984

Prepared by:

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of

Dirk and Price Engineering Limited

The views and conclusions expressed and the recommendations made in this report are entirely those of the author and should not be construed as expressing the opinions of the Alberta Department of Housing.

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FOREWORD

This study was made possible with funding provided by the Innovative Housing Grants Program of the Alberta Department of Housing. Originally conceived in 1978, the Program is intended to encourage, sponsor, and assist research and development in the fields of housing, site and subdivision design, energy conservation, site servicing and building product development. Generally, the aims of research funded by the Innovative Housing Grants Program are to reduce housing costs, increase the supply of appropriate housing or improve the utility or performance of dwelling units or subdivisions.

The main purpose of funding these studies is to examine the current issues in the field of housing and to develop innovations which offer improvements. Comments and suggestions regarding the information contained in these reports are welcome.

Innovative ideas come from a wide variety of applicants such as builders, developers, consulting firms, industry associations, municipal governments, educational institutions, non-profit groups and individuals. As the type of project and level of resources vary from applicant to applicant, the resulting documents are also varied.

Please send comments and suggestions or requests for further information to:

Innovative Housing Grants Program
Fourth Floor
10050 - 112 Street
Edmonton, Alberta
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Alberta Department of Housing
March 1984

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SUMMARY

The purpose of this project was to design, construct and monitor a domestic grey water heat recovery system.

The system consisted of an inner potable water tank submerged in an outer tank that collected hot grey water. Heat was transferred from the grey water into the potable water. The inner tank was connected so as to act as a preheater to the existing domestic hot water system.

The system has been in operation for more than one year, and has been monitored for most of this time. During this time the system has performed as expected and has contributed 26.6% of the heat required for domestic water.

Based on current electrical and natural gas prices the payback for this system would be 2.18 and 6.14 years respectively.

1. INTRODUCTION

Over the past few years energy conservation has become a concern of many households.

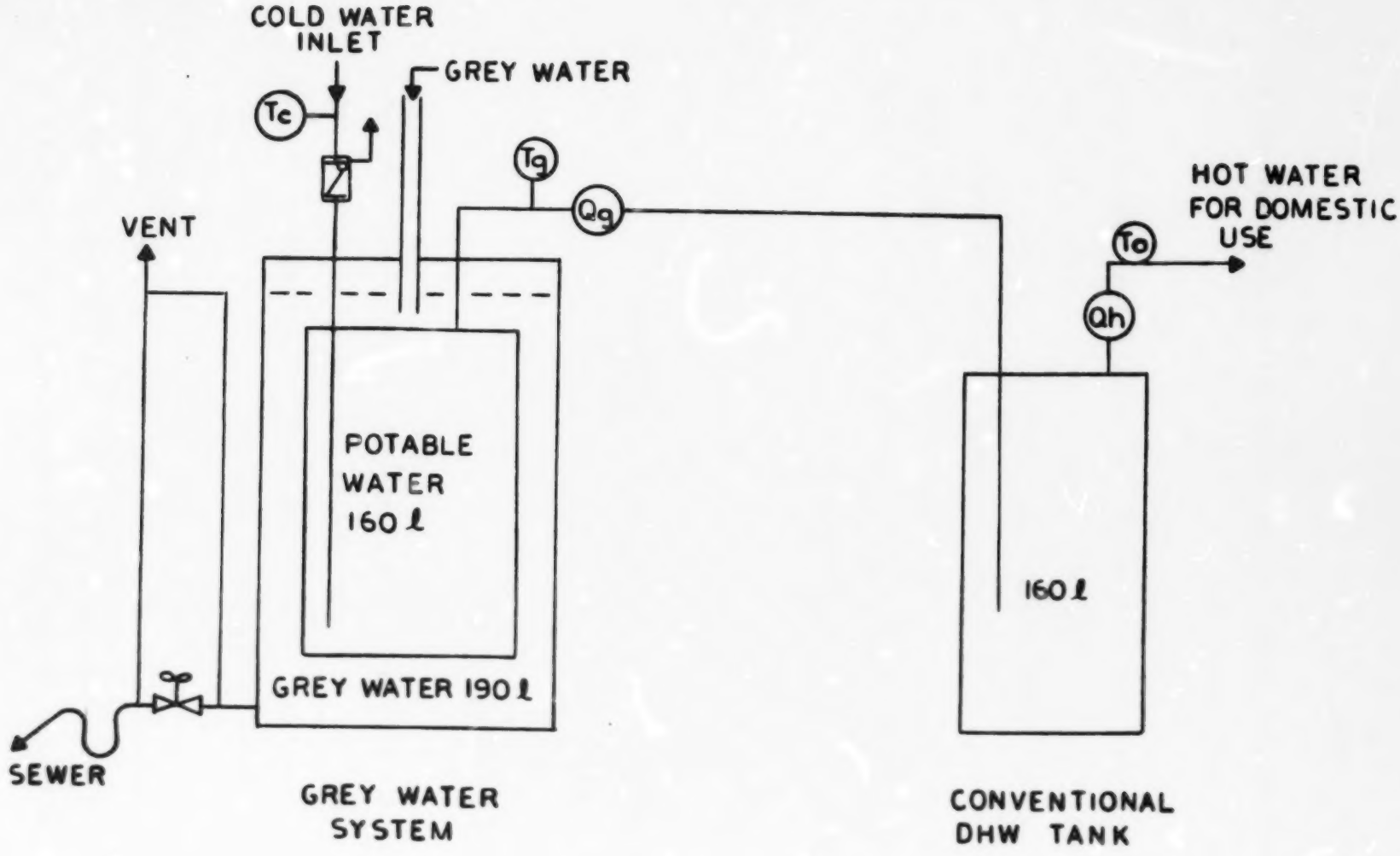
Various schemes are available to reduce the residential energy costs. Passive and active solar techniques are available to reduce space and domestic hot water (DHW) heating costs. Most domestic water heating schemes are concerned with reducing heat generation costs rather than attempting to recover energy from water that has been used for washing or bathing (grey water).

The purpose of this report is to describe a system that can be used to recover heat from grey water in an Alberta residence and to discuss the system performance based on one year of monitoring data.

2. SYSTEM CONFIGURATION

The system consists of a tank within a tank. The inner tank contains the potable water and is centrally located within an outer tank that contains grey water. A schematic of the system is shown by figure 1, page 2.

The grey water enters the outer tank at the top and completely surrounds the inner tank. The grey water outlet is at the bottom of the outer tank thereby insuring that the



GREY WATER PREHEAT FOR RESIDENTAL USE

FIGURE 1

coldest greywater is emptied to waste automatically. Potable water enters at the bottom of the inner tank and exits from the top. This tank is in series with a conventional gas domestic water heater and serves as a preheater for the conventional system.

Grey water from the dishwasher, the washing machine and the bathtub was directed to the heat recovery system. The kitchen and bathroom sinks were not connected to the system because of tank residue that would be caused by the high concentration of grease and food particles present in this water. The house in which the system was tested, contained two other showers that were not connected because of the extensive renovations that would be required to connect them.

3. SYSTEM DESIGN

The system was designed so that the grey water would enter the outer tank, mix with the existing grey water and the heat would then be transferred into the inner tank. The grey water inlet was located such that grey water flowed onto the top of the inner tank. In this way the inner tank would act as a baffle to reduce turbulence and enhance stratification.

The size of the tank was based on household appliance water capacities. Since both the dishwasher and washing machine

often operated simultaneously, it was decided that the grey water holding tank should be large enough to contain the total water used by these appliances. The dishwasher in the household used 40 liters per load and the automatic washer used 120 liters per load. Based on these two appliances and standard sizes, a 350 liter and 160 liter tank were chosen for the two tanks thus achieving a grey water holding capacity of 190 liters.

4. DESIGN EQUATIONS

A mathematical analysis was undertaken to determine the length of time required for the potable and grey water temperatures to stabilize in the two tanks.

For heat transfer by natural convection the equation -

$$* \quad q = \frac{K}{2x}\left[.17\right]\left[\frac{gBqx^4Pr}{Kv^2}\right]^{1/4} A\Delta Tm \qquad (1)$$

applies where

q = the quantity of heat transferred in watts/square meter.

K = the thermal conductivity in watts/meter/degrees Kelvin

B = 1/T where T = the absolute temperature of the liquid in degrees Kelvin.

v = kinematic viscosity of water in meters squared/second.

* Source: Holman, 1976

Pr = Prandtl number of water - no units.

A = the area of the heat exchanger surface in square meters

ΔTm = the mean temperature difference between the potable and grey water in degrees Kelvin.

X = the vertical height of heat exchanger surface in meters

g = gravity in meters squared/second.

Solving for q and evaluating for this case yields

$$q = 58.24 \Delta T$$

This equation was evaluated for various values of ΔT and yielded the graph figure 2, page 6. This analysis indicated that for grey water inlet temperatures of 38°C and potable water inlet temperatures of 7°C, 95% of the heat would be transferred in 36 minutes. The original assumption was that both the grey water and potable water had constant temperatures throughout its volume.

The energy recovered by the grey water system can be related to the various temperatures within the preheat system shown by figure 1, page 2.

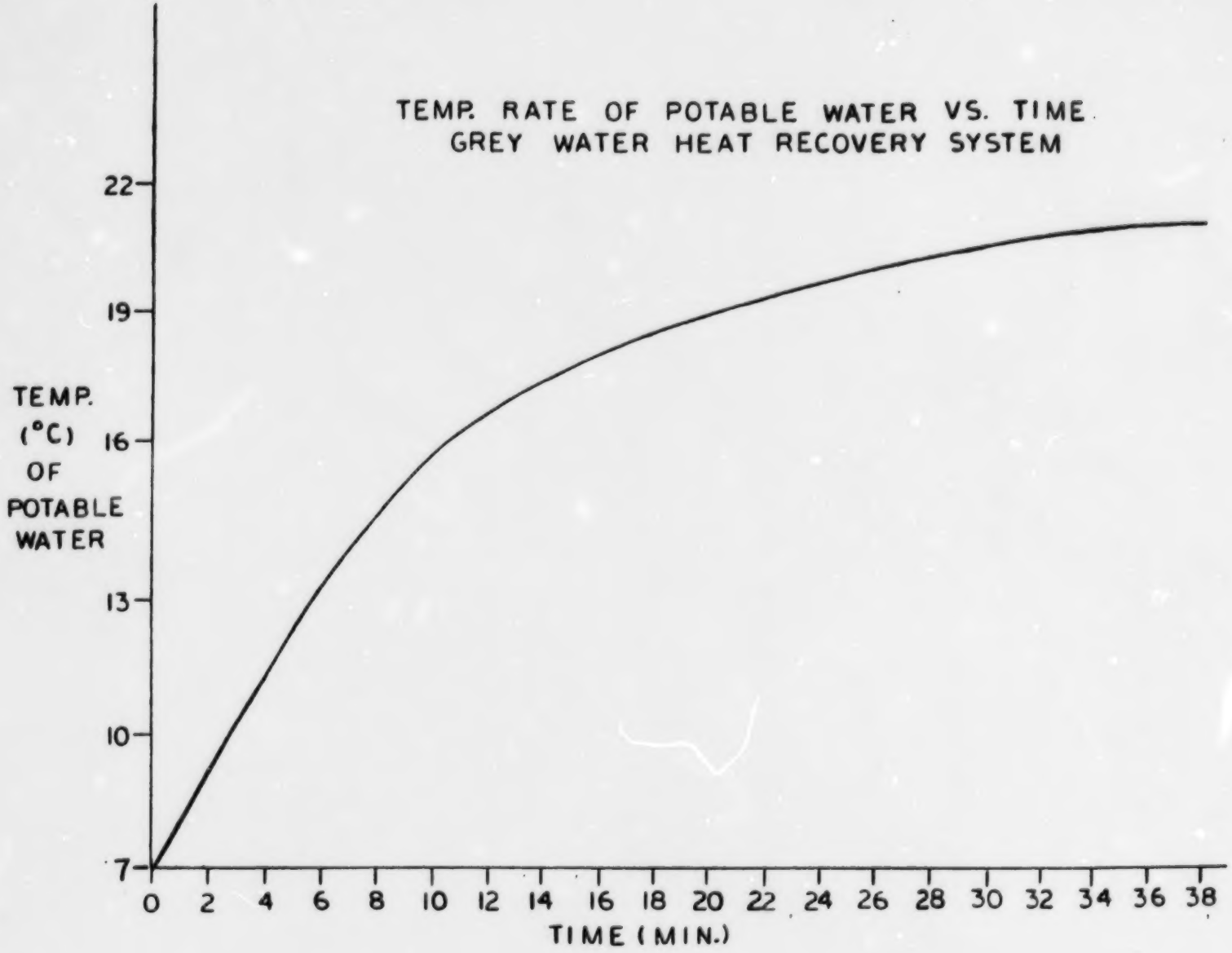

TEMP. RATE OF POTABLE WATER VS. TIME
GREY WATER HEAT RECOVERY SYSTEM
TEMP. (°C) OF POTABLE WATER
22
19
16
13
10
7
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38
TIME (MIN.)

FIGURE 2

For this system -

If $Hg = (Tg - Tc)Qg$ = heat recovered by grey water system

and $Hs = (To - Tg)Qh$ = heat supplied by the conventional system

where Tg = output temperature of grey water system

Tc = temperature of incoming city water

To = temperature of hot water suppplied to the household

$Qg = Qh$ = quantity of water used by the household

then the greywater system contribution (Gc) will be

$$Gc = \frac{Hg}{Hg+Hs} = \frac{1}{1+\frac{Hs}{Hg}}$$

and by substitution

$$Gc = 1+\left[\frac{To-Tg}{Tg-Tc}\right]^{-1} \qquad (2)$$

Equation (2) estimates the theoretical grey water heater contribution. The actual heat contribution will be reported in Section 7.4.

5. CODE REQUIREMENTS AND REGULATION REVIEW

Part 16, Division 2, rule 153 of the Alberta Plumbing and Drainage Act (1980) states that "a connection or cross connection, may not be installed, or allowed to exist, which could, under any conditions, cause or allow a potable water supply system to be contaminated, polluted or infected".

In the proposed system there are two possibilites for cross connection. These possibilites and the system protection against them are listed below.

1. When the city water mains pressure is less than the potable water pressure.

   As shown by figure 1, page 2, a back flow preventor is installed. This is to insure that no contamination can occur to the city water system.

   A potable water tank lining fault is unlikey to cause household potable water contamination since both the grey and potable water pressure at the fault point will be due to head pressure only, hence no intermingling will occur.

2. When the city water mains pressure is normal.

   A cross connection could occur if a fault existed in the potable water tank lining. Potable water contamination cannot occur as long as the potable water pressure is greater than the greywater pressure (the normal situation). This fault will be evidenced by the grey water tank continously emptying to waste.

This system has been approved by the Chief Plumbing Inspector for the Province of Alberta. For more details please refer to Appendix 2.

6. MONITORING AND INSTRUMENTATION

Figure 3 on page 10 shows the system as it was installed and instrumented.

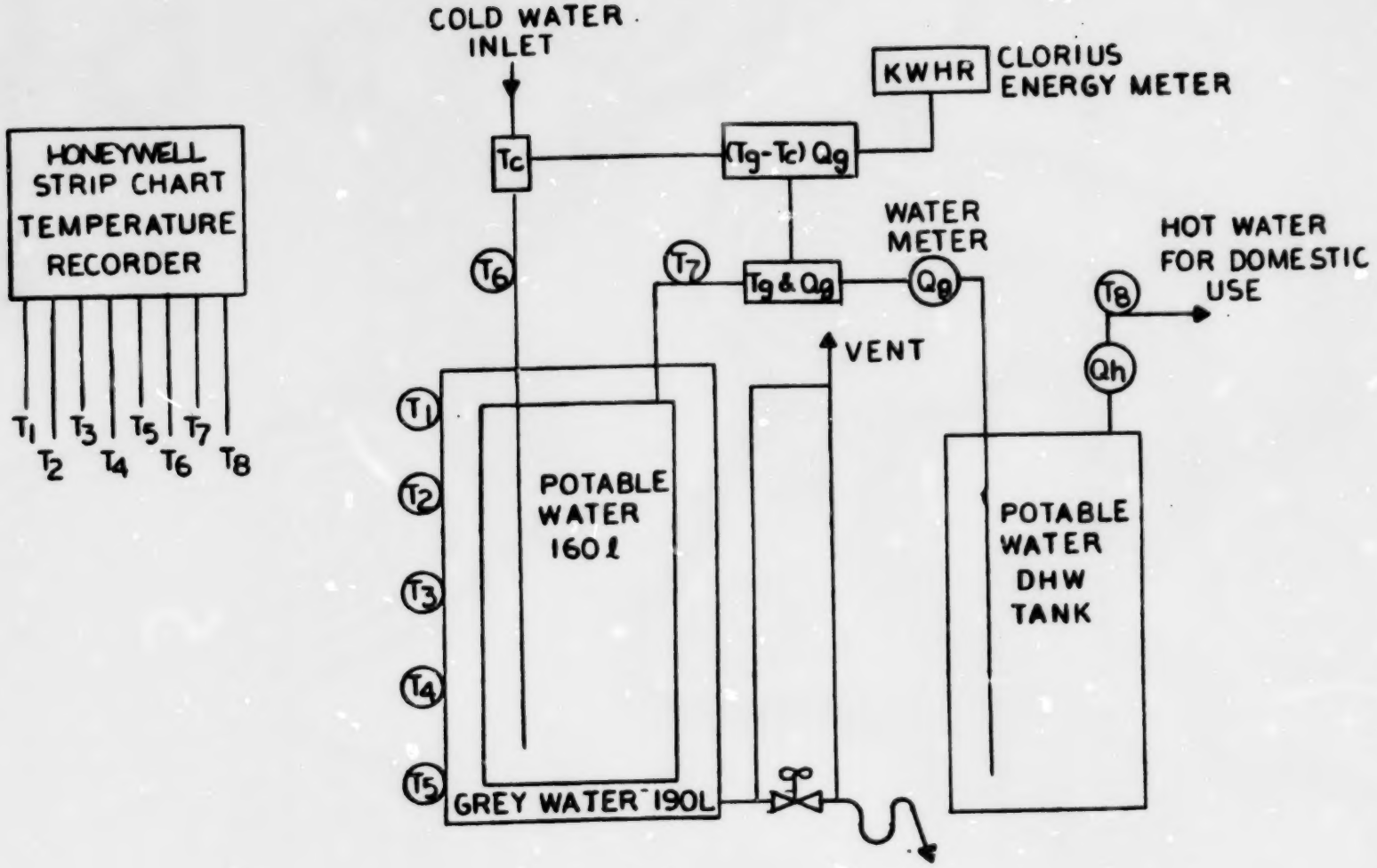
The following instrumentation was used:

Water Meter	5/8" Rockwell International Model S-21
Energy Meter	Clorius energy meter, Model 12 EM,(Billing quality)
Thermometer	Honeywell 12 channel strip chart electronic recorder

During the period February 6, 1983 to July 11, 1983 the system was continously monitored using the water meter and the energy meter. In July 1983, stratification and contribution tests were attempted, however, there was a wide discrepancy between the energy meter and the calculations using the Honeywell thermometer. The energy meter was checked for calibration and found to be in error. The energy meter was replaced with a new Model 12 EM from Denmark on October 4, 1983.

7. RESULTS

The system shown in figure 1, page 2 was installed and has been operating since February 6, 1983. During this time both the energy contributed by the system and the amount of water used was recorded except as noted in section 6. From



GREY WATER SYSTEM INSTRUMENTATION

FIGURE 3

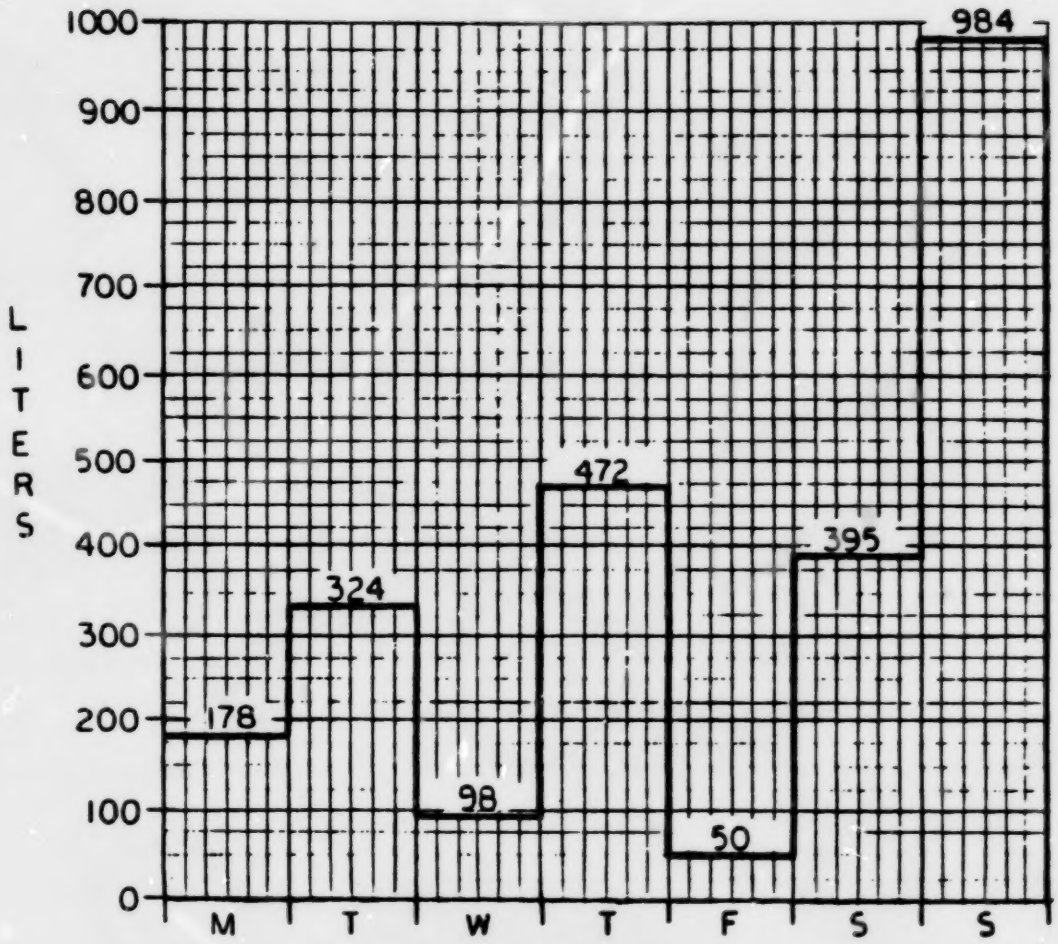
time to time temperature tests were conducted to observe the results of both stratification and the dynamic operation. The inner tank has been inspected periodically and shows no sign of corrosion. The inner tank has a coating of soapy film that tends to reduce heat transfer. An annual hot water rinse will be required to remove the film and restore heat transfer to normal.

7.1 WATER USE PATTERNS

Many references are available that discuss the amount of hot water required for the average household. Unfortunately these references do not discuss demand patterns. Figure 4 page 12 shows the daily demand for a household of 6 people (2 working adults and 4 teenage children attending school). The interesting feature of this graph is that on a weekly basis the average water required per person agrees with the literature, but of the weekly amount 55% is used on Saturday and Sunday. Since the heat recovered by the grey water system coincides with usage, this system is effective with both uniform and nonuniform water use patterns.

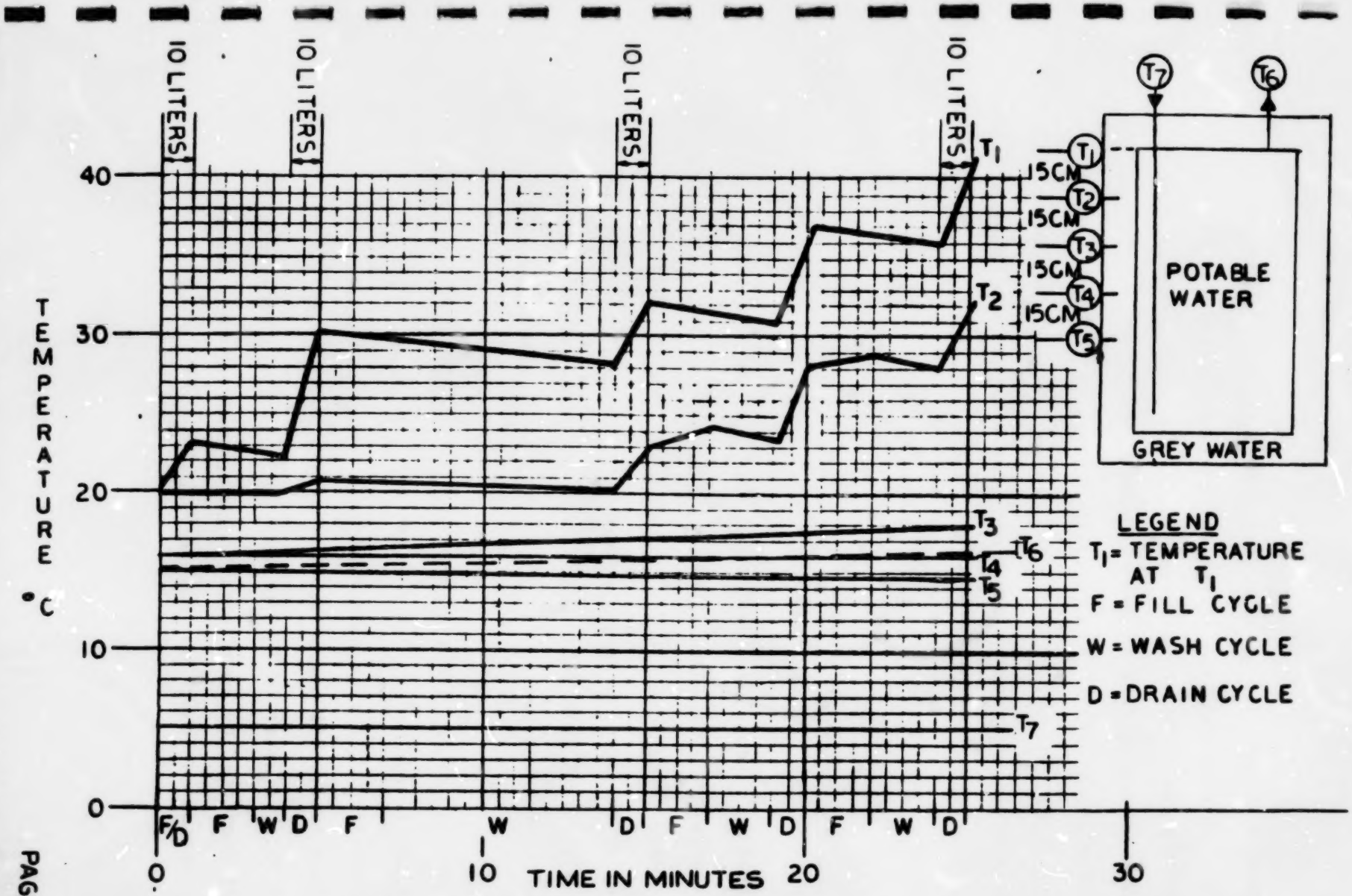
7.2 STRATIFICATION

Initial calculations assumed that both the grey and potable water in the tanks would fully mix. This was not the case. Several tests were conducted to determine the extent of stratification and the results of one of these tests is



WEEKLY HOT WATER DEMAND FOR
A 6 PERSON FAMILY (OCT. 17-23, 1983)

FIGURE 4



TEMPERATURE PROFILE OF GREY WATER DURING ONE DISHWATER CYCLE

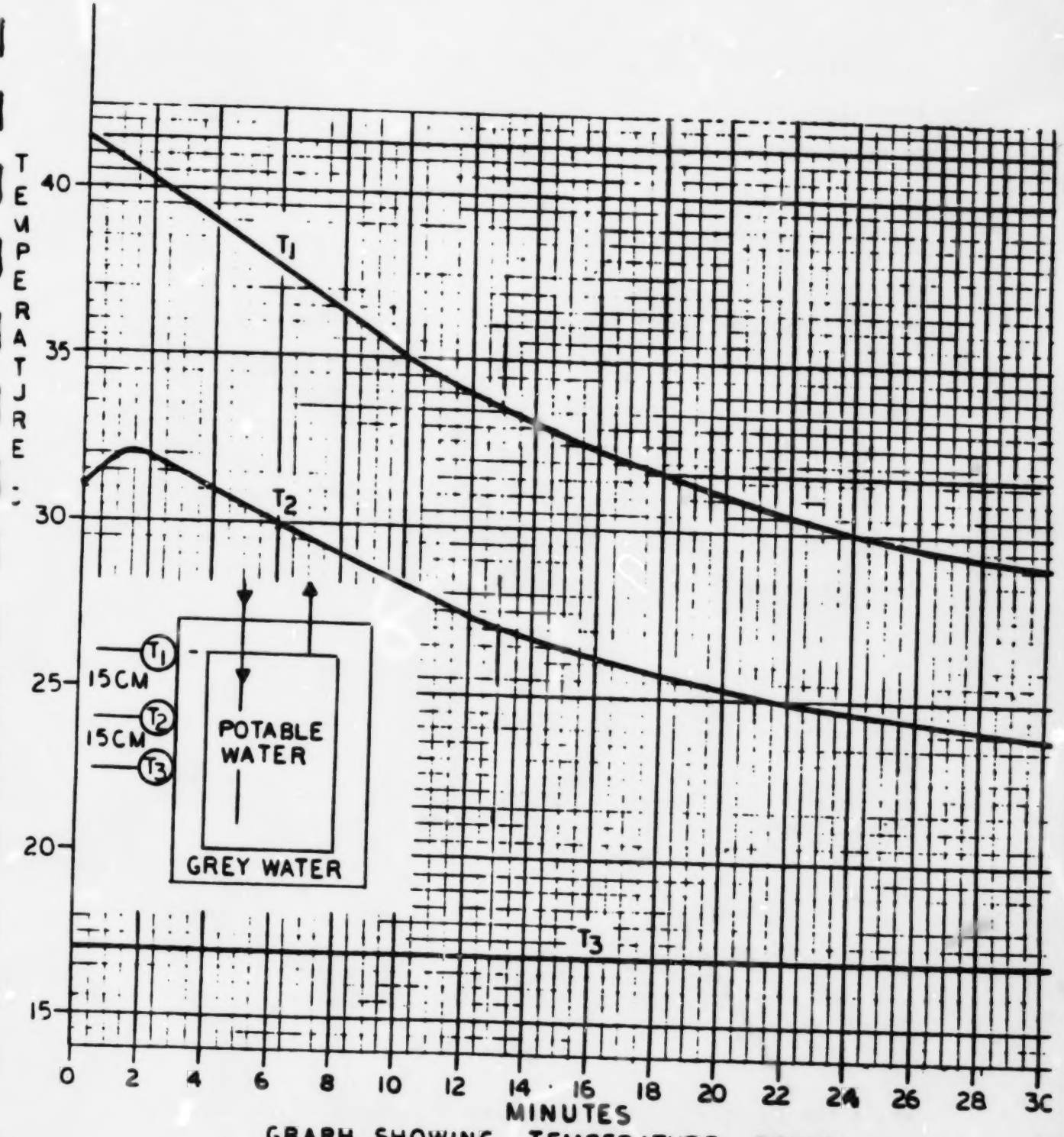
FIGURE 5

shown by figure 5 page 13. This test consisted of operating the dishwasher and monitoring the grey water temperature at various levels of the external tank. An examination of the graph indicates that as grey water is introduced, it stays at the top of the tank. Virtually no mixing occurs. This fortuitous situation results in large temperature differentials between potable and grey water at the top of the tank and therefore higher than anticipated water supply temperatures to the conventional gas heater.

7.3 TEMPERATURE DECAY TIME

Figure 6, page 15 shows the change of grey water temperature versus time after one dishwasher cycle. There is an initial increase in temperature at T2 due to the high temperature grey water layer above it, however it quickly stabilizes and this layer of warm water decreases in temperature as the heat is transferred to the potable water in the inner tank.

Since the water temperature decays exponentially it is difficult to define when all of the heat has been transferred. An examination of this graph indicated that approximately 95% of the grey water energy is transferred to the potable water in 28 minutes. This is 6 minutes quicker than predicted by equation 1, page 4, however, the original assumption was that the grey water would be fully mixed.



GRAPH SHOWING TEMPERATURE DECAY OF TOP 30CM OF GREY WATER SYSTEM FOLLOWING ONE DISHWASHER CYCLE

FIGURE 6

As indicated in Section 7.2 the grey water was highly stratified resulting in larger than anticipated differential temperatures and faster heat transfer times.

7.4 ENERGY CONTRIBUTION

As explained previously the initial energy meter was not calibrated and the readings for period February 6 - July 9 were discarded. A new energy meter was installed and the results from October 4 to December 17 indicate that 25,800 liters of water was used and 450KWHR (1620MJ) had been transferred from the grey water and used to preheat the domestic water. Table 1 below summarizes these results.

Period	Energy Recovered (KWHR)	Hot Water Usage (liters)	Liters per person per day	KWHR/wk
Oct 4-11	44	1684	40	44
Oct 11-18	38	2853	67	38
Oct 20-27	43	2547	60	43
Oct 27-Nov 3	54	3353	79	54
Oct 4 - Dec 17	450	25800	58	41.2

WEEKLY AND EXTENDED PERIOD ENERGY CONTRIBUTION DATA FOR GREYWATER SYSTEM

TABLE 1

While the purpose of this study was to determine the amount of heat recovered from the greywater, it is also of interest to determine what portion this is of the total water heating requirement.

During the period October 4 to December 17, periodic supply water and DHW tank outlet temperatures were taken. During this time the average supply water temperature was found to be 5°C and the DHW tank outlet temperature was 65 °C. On this basis we have-

The heat required to heat 25,800 l of water from 5°C to 65°C is:

$(65-5)(25800)(4185) = 6478$ MJ

The heat collected from the grey water system is 1620 MJ (Table 1)

Hence

The greywater contribution (Gc)is 1620/6478 = .25

An alternate method of calculating the contribution is to use equation 2 on page 7. Taking the DHW tank outlet tank temperature at 65°C, the supply water temperature at 5 °C, and the outlet temperature of the greywater system at 21 °C the contribution will be;

$$Gc = 1 + \frac{1}{\left[\frac{T_o - T_g}{T_g - T_c}\right]} = 1 + \frac{1}{\left[\frac{65-21}{21-5}\right]} = \frac{1}{3.75} = .266$$

This figure is somewhat higher than that calculated previously however the equation used assumes that all of the temperatures are constant and this is definitly not the

case.

This method does serve as a check and will not be exactly the same as the results from integrating type meters.

7.5 LIFE CYCLE COSTS

The payback period depends upon the type of fuel used to generate hot water in the home. For Calgary the cost of fuel for 1984 is;

Electrical energy	$.05/KWHR ($13.9/GJ)
Natural gas	$2.63/GJ

It is estimated that the installed cost of the greywater system would be $300 in a retrofit or $225 if the system were mass produced and installed in a new house at the time of construction.

As indicated under section 7.4 the energy saved is 148 MJ/week or 7.7 GJ/yr.

The life cycle costs have been calculated using the equations of appendix 4 where;

FC = $225
FYS = 7.7(13.9) = $107 (electricity @ 100% eff.)
= 7.7(2.63)(1.66) = $33.6 (gas @ 60% eff.)
i = 6%
e = 10%
n = 20 years

Table 2 shows the life cycle costs for both electricity and gas.

	Electricity	Gas
FC	$225	$225
FYS	$107	$ 33.6
PB	2.18 yrs	6.41 yrs
PV	$2936	$922
FV	$8695	$2235
NR	20%	12%

LIFE CYCLE COSTS FOR
A GREY WATER SYSTEM

TABLE 2

FC = system installed cost

FYS = amount saved in first year of operation

i = interest rate on deposited savings

e = energy escalation rates

n = life of the system in years

PB = payback

PV = present value

FV = future value

NR = net return

Based on the above analysis the installation of a grey water system is an attractive investment. If the energy source is electricity then an investment of $225 now will result in savings which if invested will grow to $8695 in 20 years. This is equivalent to investing $225 at 20% for the next 20 years. If the fuel is natural gas then the net return is 12%.

8. MAINTENANCE

The maintenance on this system will be minimal. If both tanks are made of galvanized steel the life of these tanks should be at least 20 years. Temperatures are low and corrosion will be inhibited somewhat by the coating due to soapy water film on the inner tank. The system should have a removable top to enable the exterior of the potable water tank to be rinsed annually.

9. PRACTICAL PROBLEMS

The system is very functional and requires little attention. The experimental system did not have a vapor tight top and occasionally an unpleasant smell was emitted by the system. A commercial system must have a vapor tight top and also the drain must be plumbed into a trap and vent as shown by drawing B82H039 in appendix 1.

10. CONSIDERATIONS FOR FURTHER STUDY

An unexpected result was the extreme stratification that occurs. In the heat recovery system described in this paper this is a distinct advantage. Because of the stratification, temperature differentials at the top of the two tanks are large hence heat transfer time is decreased. An interesting modification to the proposed system would be

to have the inner tank extend beyond the top of the outer tank. When hot grey water is introduced, the heat would be transferred to the inner tank, the warmed water in the inner tank will rise, and be replaced with cooler water. In this way higher temperature differentials could be obtained between inner and outer tanks by enhancing conduction. The extended inner tank would be insulated and a pool of heated water would be trapped at the top of the inner tank. It is anticipated that with this modification and the connection of all showers and bathtubs to the system the contribution could be increased by 5-6%, resulting in a payback period of 2 years and 6 years for electricity and natural gas respectively.

11. COMMERCIAL APPLICATIONS

This system is suited for any establishment that uses hot water and then drains it to waste. More plumbing may be required in commercial applications because the equipment would likely be on the same floor. Additional holding tanks and pumps might also be required to transfer the grey water to the heat recovery system.

A particularly suitable commercial application is that of laundromats. Each washer has an integral pump that would be suitable for pumping the grey water into the system. In all cases care must be taken to insure that a tall slim tank be used in order to maximize stratification.

B I B L I O G R A P H Y

Carter, Joe and Robert G. Flower

1980 "The Micro-Load," Solar Age Volume 5, Number 9.

Dumont, R.S. and R.W. Besant

1978 "A Grey Water Heat Recovery Unit for Domestic Residences." University of Saskatchewan Department of Mechanical Engineering, Saskatoon, Saskatchewan.

Ebersbach, Karl F.

1977 "Heat Recovery from Waste Water in Domestic Buildings," presented at the Energy Use Management International Conference, Tucson, Arizona.

Fogel, H

1979 "The Treatment of Household Greywater in Homes Equipped with a Clivus Multrum Organic Waste Treatment System".

Holman, J.P.

1976 "Heat Transfer", McGraw Hill,4th Edition.

Milne, Murray

1976 "Residential Water Conservation", California Water Resources Centre, University of California/Davis.

Nelson, Glenn

1981 "Greywater Heat Recovery", Clivus Multrum Northern Rockies.

Nelson, Glenn

1981 "Greywater Heat Recovery," published in Solar Age.

Pemberton, Eric

1980 "A Residential Heat-Recycle Water Heater," prepared for the Canadian Electrical Association by Electrohome Ltd.

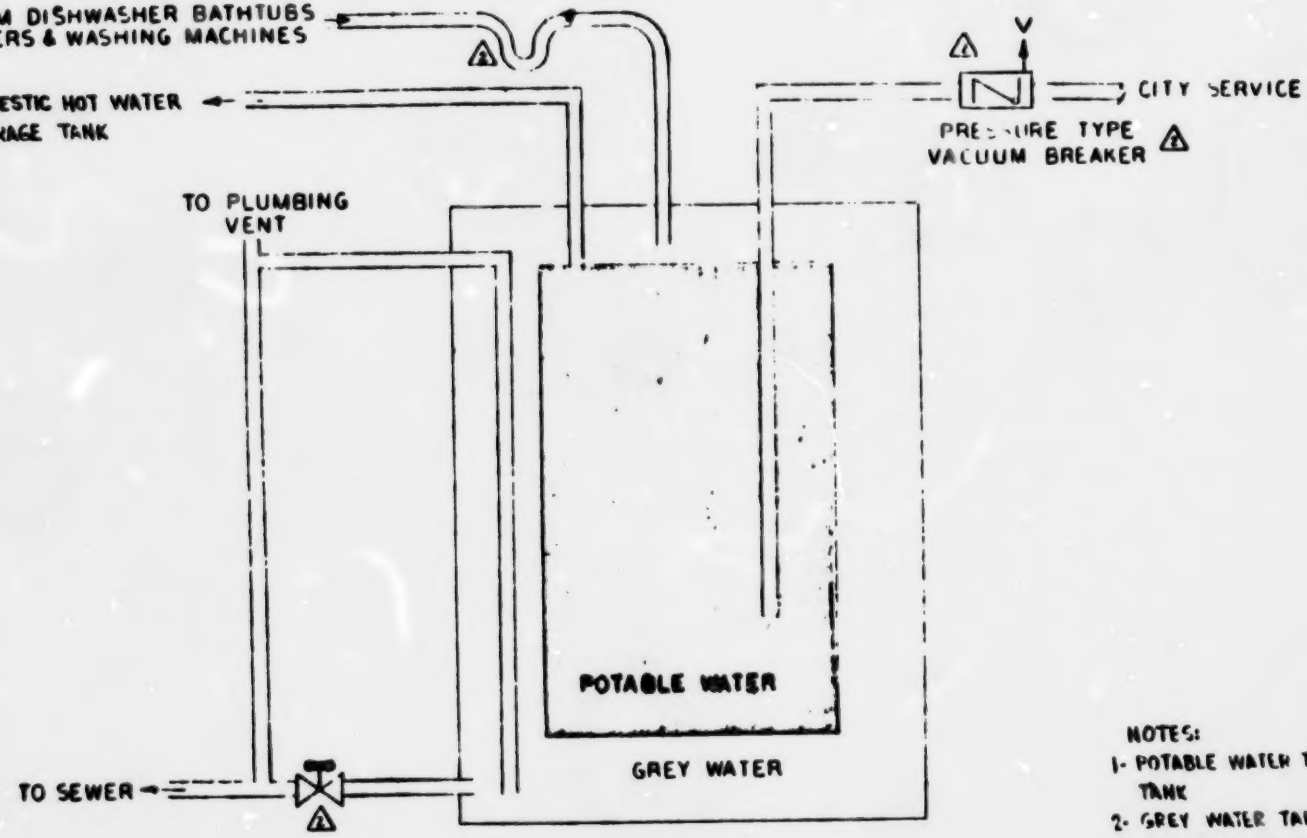
Rekken, G.M. and Howell,D.G.

1983 "Assessement of Energy Saving Measures Used in the ER-1 Conservation/Solar Research House". Innovative Housing Grants Program, Alberta Department of Housing, Edmonton Alberta.

1980 Saskatchewan Conservation House Final Report, Saskatchewan Mineral Resources, Office of Energy Conservation.

1980 "The Plumbing and Drainage Act Regulations", General Safety Services Division, Plumbing Inspection Branch, Edmonton Alberta.

Appendix 1



NOTES:
1- POTABLE WATER TANK TO BE A GALV. STEEL PRESSURE TANK
2- GREY WATER TANK TO BE EPOXY LINED STEEL TANK
3- PIPING TO BE ABS OR PVC SCHEDULE 40

GENERAL NOTES	NO	REVISION	BY	DATE	CHD
	1	[illegible]			
	2	[illegible]			

DIRK & PRICE ENGINEERING LTD.
CALGARY, ALBERTA

GREY WATER HEAT RECOVERY SYSTEM

BY DATE	DRAWN	CHECKED	APPROVED	APPROVED	SCALE	DRAWING NUMBER	REV
	[illegible]				—	B-62H-038	2

Appendix 2

Alberta
LABOUR
General Safety Services Division
Plumbing and Gas Safety Services
Branch

10808 - 99 Avenue, Edmonton, Alberta, Canada T5K 0G5 403/427-8256

1983 12 23

DIRK & PRICE ENGINEERING LTD.
3415 - 3rd Avenue S.W
CALGARY, Alberta
T2N 0M4

Attention: Mr. C. R. Price

Dear Sir:

Re: Grey Water Heat Recovery System

We have examined your plan B82H039 for a heat recovery system and condlude after our telephone conversation with you that it is acceptable.

However, I feel that the double check valve on the water supply line should be replaced with a pressure type vacume breaker in order to prevent possible back siphonage into the water supply, should a reupture occur in the potable water tank.

Yours truly,

D. P. Carritt
Chief Plumbing Inspector

DPC/ds

(b) a device that is designed to automatically shut off the electricity or fuel supply to the tank when the water in the tank reaches a predetermined temperature.

(3) Every tank equipped in accordance with subsections (1) and (2) shall bear the information in a clearly visible location that it is so equipped. (AR 340/77)

148. (1) The outlet of a temperature relief valve, a pressure relief valve or a combined temperature and pressure relief valve on a service water heater shall be provided with a pipe having the same diameter as the diameter of the valve outlet and shall terminate within 300 mm (1 ft.) of the floor.

(2) A shut-off valve shall not be installed on the pipe between the tank and the relief valves and a restriction or reduction of pipe size shall not be placed on the outlet of the relief valve. (AR 340/77; 295/80)

149. A back-siphonage device shall be installed when required by an inspector. (AR 340/77)

150. Every valve shall be readily accessible for service or replacement. (AR 340/77)

151. Air chambers or shock stops shall be installed in conjuction with spring-action or quick-closing valves and taps to prevent water hammer. (AR 340/77)

152. Shock stops that are of a mechanical nature shall be located in an accessible place. (AR 340/77)

Division 2

Protection of Potable Water Supply from Contamination

153. (1) A connection, or cross connection, may not be installed, or allowed to exist, which could, under any conditions, cause or allow a potable water supply system to be contaminated, polluted or infected.

(2) Where, in the opinion of the inspector there are abnormal conditions, or where the method of backflow prevention is not clearly indicated in these regulations, the method to be used to protect the potable water supply shall be approved in writing by an inspector.

(3) Subject to subsection (2), all backflow prevention devices shall be installed as specified in Table L. (AR 340/77)

154. All backflow prevention devices shall conform to the appropriate C.S.A. Standard. (AR 340/77)

155. A newly installed part of a potable water supply system shall be thoroughly cleaned and disinfected to the satisfaction of the inspector before such system is put into use. (AR 340/77)

Appendix 3

APPENDIX 3

The equations used in life cycle costs use the following symbols and equations:

FC = system installed costs

FYS = the amount saved in the first year of operation

i = the interest rate on deposited savings

e = energy escalation rates

n = the life of the system in years

PAYBACK (PB)

The length of time required for the accumlated savings to equal the installed value.

$$PB = \frac{\log \left[\frac{1}{1-(i-e)\left(\frac{FC}{FYS}\right)} \right]}{\log \left(\frac{1+i}{1+e} \right)}$$

PRESENT VALUE (PV)

The amount of money deposited now at an annual interest rate (i) such that the interest generated would provide the anticipated annual savings taking into account an annual escalation in energy rates of (e).

$$PV = FYS \left[\frac{1-\left(\frac{1+e}{1+i}\right)^n}{1+i} \right]$$

FUTURE VALUE (FV)

The amount of money that will accumlate over n years if the savings are deposited at interest (i).

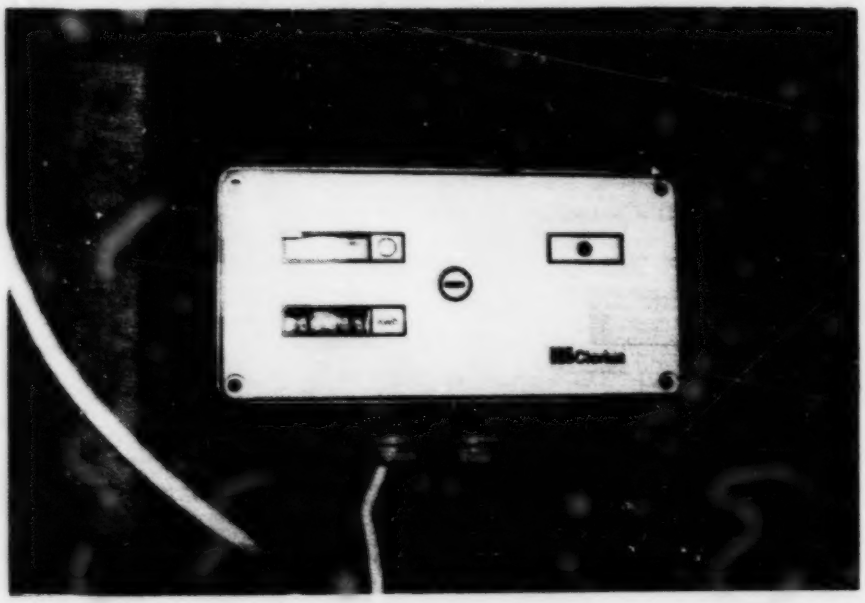
$$FV = (PV - FC)(1 + i)^n$$

NET RETURN (NR)

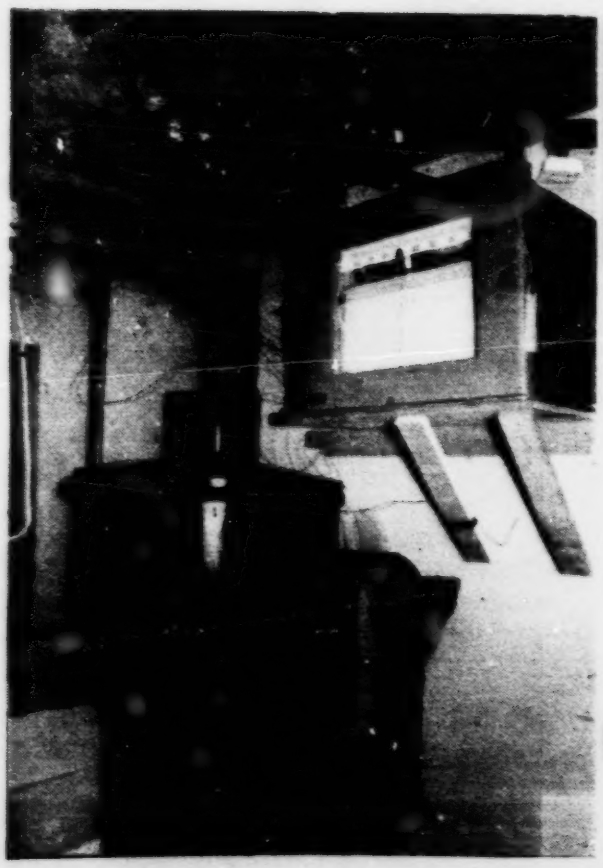
The interest rate on a deposit of FC that would produce the amount FV in n years.

$$NR = \left(\frac{FV}{FC}\right)^{1/n} - 1$$

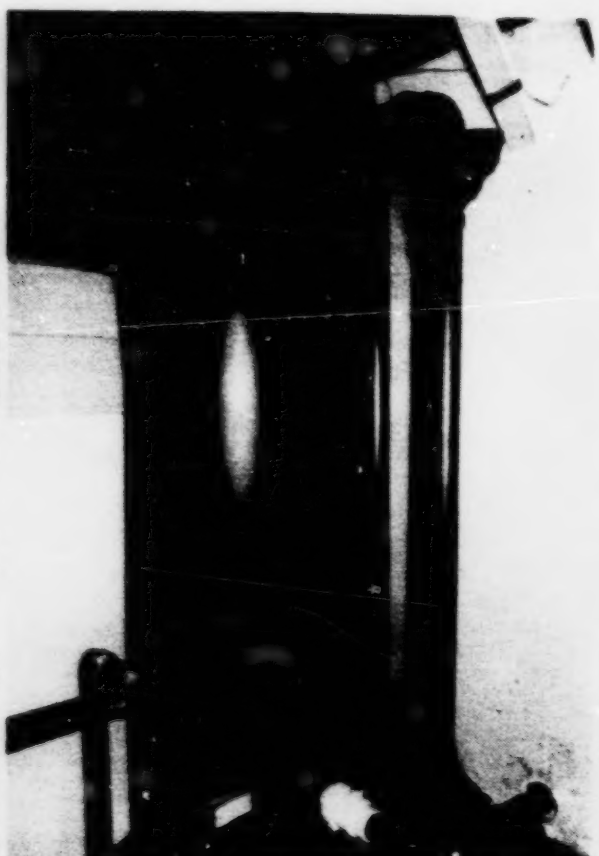
Appendix 4



CLORIUS ENERGY METER



HONEYWELL STRIP CHART
RECORDER CONNECTED
TO SYSTEM



GREY WATER SYSTEM
SHOWING INVERTED "U"
AND DRAIN VALUE